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Notices of the Royal Aëronautical Society.

The Syllabus.

The lectures arranged for the Society's session 1919-20 will begin on October 29th next with an address by Sir Horace Darwin, F.R.S. The lectures will be held fortnightly and as in former years in the Theatre of the Royal Society of Arts. Details will be announced shortly.

The Scottish Branch.

The inaugural meeting of this branch of the Society was held in the St. Andrew's Hall, Glasgow, on September 24th, when short addresses were given by Lord Weir, Major G. H. Scott, C.B.E., Major Cooke, A.F.C., Lieutenant Guy Harris, A.F.C., and Lieutenant J. D. Shotter, A.F.C. The chair was taken by Sir William Beardmore, Bart., the chairman of the Scottish Branch.

Appointments.

The Lord President of the Council has appointed Professor Joseph Ernest Petavel, D.Sc., F.R.S., M.I.Mech.E., etc., to be Director of the National Physical Laboratory in succession to Sir Richard Glazebrook, C.B., F.R.S., who retires on reaching the age limit on September 18 next.

Professor Petavel is Professor of Engineering and Director of the Whitworth Laboratory in the University of Manchester. He is a member of the Advisory Committee for Aeronautics of the Air Ministry. He was educated at University College, London, and undertook scientific research at the Royal Institution and at the Davy Faraday Laboratory until 1898. He was elected John Harling Fellow of the Owens College, Manchester, in 1900, and was Scientific Manager of the Low Temperature Exhibit of the British Royal Commission for the St. Louis Exhibition, 1904.

Lieutenant-Colonel B. Melville Jones, Associate Fellow, has been elected to the Francis Mond Professorship of Aeronautical Engineering at Cambridge University.

Ex-Service Men.

The Minister of Labour requests us to give prominence to the following appeal:—

"On behalf of the ex-Service men who laid aside their careers at the call of duty, I make a strong appeal to you to aid them to fit themselves fully for the highest posts in the great professions.

"The Government have decided to supplement private effort by means of maintenance grants under the Training Grant Scheme, which has been described in the Press and elsewhere. Training for professional qualification is usually best undertaken by service in an office or works, and it is in many cases the custom to charge a premium for pupils who take up such service. More openings for training are urgently wanted, and many ex-Service men cannot now afford to pay premiums.

"These men have proved themselves ready to give up everything. Their sacrifice cannot be measured in money. But it can be repaid in part. I urge you to think of your debt to them as their premium, and to waive for them the usage of the profession as many public-spirited firms have already done.

"For over four years the normal supply of fully trained men has been stopped or diminished. More must be obtained in the next few years than ever before, if the profession is to recover its strength and face the economic struggle that is before the whole nation. I ask you, therefore, to make room for pupils to the utmost of your capacity and to aid the Appointments Department in the work of resettlement by telling them of what you can do to help."

AIR NAVIGATION.

BY MAJOR H. E. WIMPERIS, R.A.F.

The subject of air navigation has been chosen because with the ending of the war this becomes the most important of the unsolved problems relating to aviation. It is unsolved mainly, I think, because the actual operations of the war, apart from certain individual efforts of great merit, did not reach the point at which really long flights were made. Had the activity of the war continued there is little doubt that long distance air navigation would have been impelled to as high a degree of actual achievement as was attained by other branches of the new science of aeronautics.

It happens that one particular aspect of the navigation problem did indeed attract quite a considerable amount of attention during the war; and it may surprise some of my audience to learn that the problem of bomb-dropping is one of navigation in miniature. A little reflection will show that this must be so. It is essential that the course-made-good horizontally by the released bomb shall carry it correctly to its target, and moreover that this journey shall be completed in a period of time precisely equal to that occupied by the falling bomb in its vertical descent to the earth. This course-made-good may happen also to be the course steered, but this is exceptional and will occur only in up or down wind attacks. In general the attack will be in any direction relative to the wind and the course-made-good will therefore be totally different to the course steered. Any increase in the intensity and accuracy of anti-aircraft defence makes it more than ever necessary to attack across wind: and it therefore follows that bomb sighting requires a solution of the very same horizontal vector triangle of aircraft motion as falls to the air navigator. Thus, it happens that the most important form of air navigation, that called "dead reckoning" or "D.R.," has already received much more attention during the war than would have fallen to it for air navigation pure and simple.

Navigation in practice sometimes requires no more of the airman than recognising the towns, rivers, and railway junctions near which he flies, much as an automobile driver would do. Of this simple form of the art nothing more need be said. Sometimes, however, the land will be obscured by cloud or fog; sometimes the course will lie across the ocean; sometimes across deserts. If the safety of the craft and its crew is to be reasonably assured in each of these cases, provision must be made for navigation by the very best scientific methods available.

Figure 1 is a map prepared by the American journal "Aeronautics" to show alternative routes for crossing the Atlantic. I include it because it affords a good illustration of the need for accurate navigation. Suppose an aircraft starts from Newfoundland on the 1,200 mile flight to Flores in the Azores; an error of no more than three degrees in the course-made-good would lead the craft 60 miles astray by the time the neighbourhood of the island was reached; as will be seen from the map such an error might lead to consequences very serious to the navigator.

With this diagram before us it is worth while to visualise the all important meteorological fact that an aircraft able to select its route and altitude of flight in such a way as to have a 30 mile an hour wind behind it would shorten its journey by 720 miles in each 24 hours of flight. On a trans-Atlantic crossing this would immensely increase the ease and safety of the passage. It appears from a study which has been made of the prevailing Atlantic winds that of the routes shown on the map, the upper route is on the average the more favourable for an eastward crossing, whilst for a favourable westward one a

route further south than the most southerly one shown, and therefore much longer, would be necessary. The middle one shown involves a "jump" of nearly 2,000 miles, which, without the assistance of a favourable wind, is on the limit of what is feasible for an aeroplane of the present day. It is well within the range, however, of a rigid airship of the No. 33 class; and General Maitland has given his opinion that it would be possible to build a commercial airship equal to this range even when carrying 12 to 15 tons of cargo. A more speculative suggestion has been made elsewhere of an airship—not of 2,000,000 but 10,000,000 cubic feet capacity—capable of a range of 20,000 miles and having a freight capacity of as much as 200 tons.

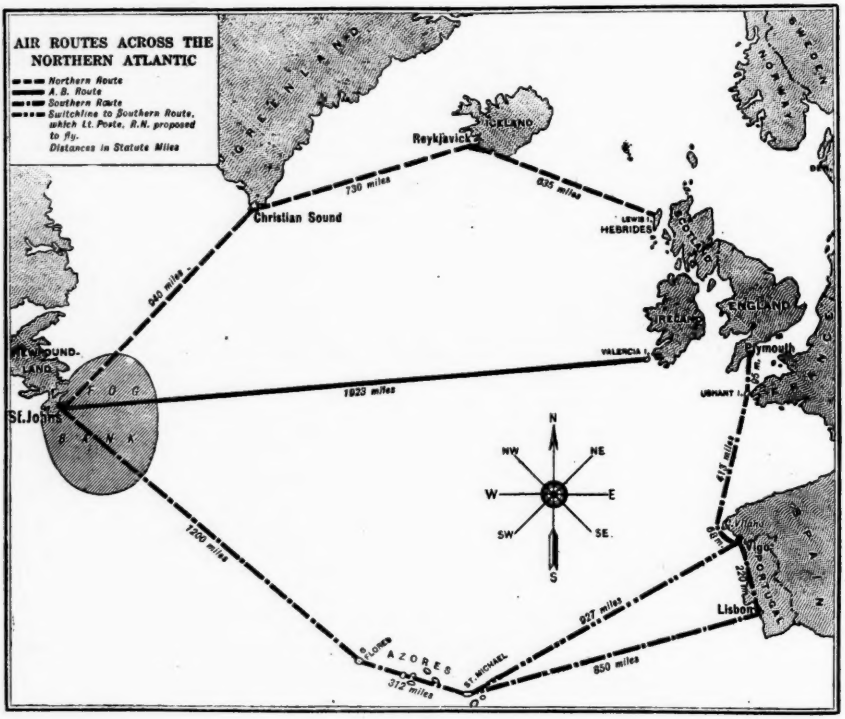


FIG. 1.

So many sides are there indeed from which the problem of the navigation of the air can be viewed, that there scarcely seems any limit to the subject, and therefore to the time which a lecture such as this might occupy. Fortunately in the mass of the problems which press for discussion and solution there are certain important groups which can be seen whole and the one which has been selected for this present purpose is the actual navigator's work in planning an air voyage and in making the necessary observations en route—particularly in those features wherein his work differs from that of the sea navigator.

Sea Craftsmanship.

All navigation begins with the sea. In the early days of sailing ships a knowledge of the surface winds in all parts of the navigable oceans was of first

importance. Such knowledge was entirely empirical and those who possessed it thought little indeed of such effects as surface friction and still less of the then unrealised importance of the weather conditions tens of thousands of feet above them. Coupled with an empirical knowledge of the average behaviour of surface wind was an empirical knowledge of the ocean tides.

With the advent of the higher speeds of steam driven ships the tides became of less importance as a factor deflecting the ship from its course, although the greater momentum due to swifter motion made the penalty of misjudgment very much heavier.

Aircraft are concerned with another ocean—that of the air itself. Its tides are far less easy to predict than the tides in the sea and are of far, far higher velocity. Its tides are the winds themselves and their intensity may range to 100 miles an hour or even more. Here are no permanent tide charts to guide the would-be navigator, be his need ever so pressing. Long experience of surface winds had enabled his maritime predecessor to form some rough judgments of the ways of such winds, thus Conrad* tells:—

> "The narrow seas around these isles, where British admirals keep watch and ward upon the marches of the Atlantic Ocean, are subject to the turbulent sway of the west wind. Call it north-west or south-west, it is all one—a different phase of the same character, a changed expression on the same face. In the orientation of the winds that rule the seas, the north and south directions are of no importance. The north and south winds are but small princes in the dynasties that make peace and war upon the sea. They never assert themselves upon a vast stage. In the polity of winds, as amongst the tribes of the earth, the real struggle lies between east and west. The end of the day is the time to gaze at the kingly face of the westerly weather, who is the arbiter of ships' destinies. Benignant and splendid, or splendid and sinister, the western sky reflects the hidden purposes of the royal mind. Clothed in a mantle of dazzling gold or draped in rags of black clouds like a beggar the might of the westerly wind sits enthroned upon the western horizon with the whole North Atlantic as a footstool for his feet and the first twinkling stars making a diadem for his brow."

But we cannot count that the long experience of the mariner, however hardly won and however powerfully expressed, will apply in the upper air; the formulation of even rough rules may prove not to be possible, and whether possible or not, certainly they are as yet unrevealed. Meteorology, ever willing to help but sometimes lacking the means, is at last being placed in a position in which it can include in its wide world survey the study of the winds of the upper air. Such study is absolutely essential to the future of air navigation and that this is beginning to be realised, witness the daily publication since 21st January last in the "Times" of tables of the "Wind Direction and Velocity in the Upper Air." The next slide shows this table:—

AVIATION WEATHER.

MONDAY, JANUARY 20TH, 1919.—MORNING OBSERVATIONS.

WIND DIRECTION AND VELOCITY IN THE UPPER AIR.

	Height above ground.			
District.	2,000ft. m.p.h.	5,000ft. m.p.h.	10,000ft. m.p.h.	15,000ft. m.p.h.
Scotland, E. ..	S. 22	S. 28	—	—
England, N. ...	S.S.E. 37	—	—	—
England, N.W.	S.S.W. 14	S.W. 13	—	—
England, E. ...	—	S.S.E. 19	N.W. 43	W. 23
Ireland, S.W....	—	—	—	—

* "The Mirror of the Sea."

Velocities are given in miles per hour. Note here the importance of choosing the right level in which to fly. On this day in the eastern counties the wind at 5,000ft. was but 19 m.p.h., whereas at 10,000ft. it was more than twice as much, whilst at 15,000ft. the velocity had almost sunk to that at the 5,000ft. level. Here the wind is seen first to increase with height and then to decrease, whilst the direction also changes considerably. But the more variable are the weather conditions the more necessary is it to have the right sort of meteorological information before setting out on a long air voyage.

Allowance for Wind.

It is easiest to allow for the effect of the wind by considering the aircraft to move straight ahead through still air, and then to consider separately the simul-

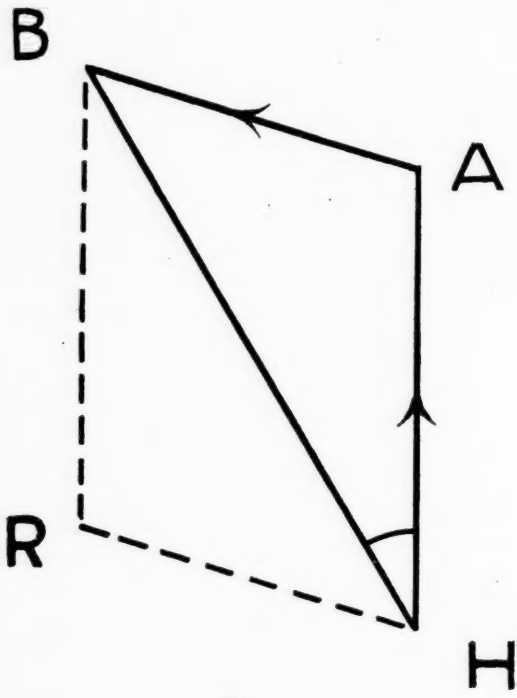


FIG. 2.

taneous shift—which we call wind—of this air ocean relative to the earth. If for instance an airplane starting from Hendon, heads due north for an hour at an air speed of 100 miles an hour, it would, if there were no wind, then find itself 100 miles north of Hendon, but if in the meantime there had existed a uniform wind such that the air in which the machine mounted at Hendon had since arrived at Reading, the airplane would at the end of the hour find itself 100 miles north, not of Hendon but of Reading. Thus, in Figure 2 the machine flies from H to A whilst the air moves from H to R and from A to B; so that at the end of the hour the machine finds itself not at A but at B. This is called a vector diagram and the velocity vector HA is said to be added to the wind velocity vector AB giving HB as the answer.

Evidently this means also that a machine wishing to fly from H to B must set its head along the direction HA and not in the direction HB; the angle AHB, the angle between the course steered and the course-made-good, is a very important one and known as the angle of drift. HA is the course steered and HB the course-made-good.

Note that on an "out and home" journey in the same wind and at the same airspeed the drift angles out and home will be equal. Thus, to fly from A to C (Figure 3), when the wind is equal to BD in velocity and direction means setting the head of the machine along AB on the outward flight and along CB on the home flight. Then as AB and BC are equal the angles of drift (BAD and BCD) must also be equal. Thus, if a navigator knows the right angle of drift to allow for on his outward journey, he also knows it for his home journey if the same conditions as to wind and air speed remain.

So if air speed be known and wind be known, and a good compass be available, the navigator is in the easy position of being able to predict his position from hour to hour with complete precision. He is in the same position as would be the navigator of a ship who knew the record of his log and the precise effect of the tides. The maritime navigator makes use of this knowledge—or of the best approach he can make to it—by plotting on his chart the position his ship would be in were there no tides at all and this he calls the "dead reckoning" or D.R. position. He then corrects this position for the effect of the assumed tides and so arrives at his "estimated position." This needs always to be recorded in the log no matter whatever other navigational methods may be employed as a check. The importance of keeping note of the D.R. and estimated positions has long been known; thus, in Hakluyt's voyages we find the following graphic "instruc-

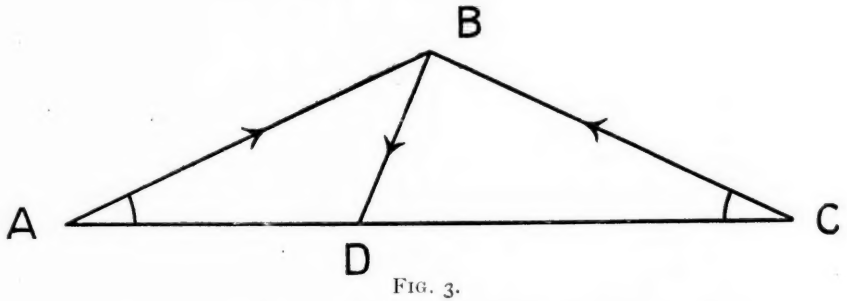


FIG. 3.

tions and notes very necessary and needful to be observed" and dated 1580:—

> "When you come to Orfordnesse, if the winde doe serve you to goe a seabord the sands, doe you set off from thence, and note the time diligently of your being against the saide Nesse, turning then your glasse, whereby you intende to keepe your continuall watch, and apoint such course as you shal thinke good, according as the wind serveth you. And in keeping your dead reckoning, it is very necessary that you doe note at the ende of every foure glasses, what way the shippe hath made (by your best proofes, to be used) and howe her way hath beene through the water, considering withall for the sagge of the sea, to leewards, accordingly as you shall finde it growen. Doe you diligently observe the latitude as often, and in as many places as you may possible; and also the variation of the compasse (especially when you may bee at shoare upon any land) noting the same observations truely, and the place and places where, and the time and times when you do the same. Afterwards when you have sailed 1, 2, 3 or 4 glasses (at the most) noting diligently what way your barke hath made, and upon what point

of the compasse, do you againe set that first land seene, or the parts thereof, that you first observed, if you can well perceive or discerne them, and likewise such other notable points or signes upon the land that you may then see, and could not perceive at the first time, distinguishing it also by letter from the other, and drawing in your booke the shape of the same land, as it appeareth unto you, and so the third time, etc. Thus, I beseech God Almightie to bless you, and prosper your voyage with good and happie successe, and send you safely to returne home againe, to the great joy and rejoycing of the adventurers with you, and all your friends, and our whole countrey. Amen."

Our air navigator needs to keep his D.R. position just as carefully, but he is in the more fortunate position in that he can almost always determine the velocity and direction of the wind (his aerial "tides") from time to time by observation on the visible earth beneath. The ship navigator could only do this if the sea were transparent and he could see the bottom of the ocean and so observe and measure his angle of drift. The air navigator can almost always count on obtaining a glimpse, from time to time, of the earth and so check his current estimate of the wind.

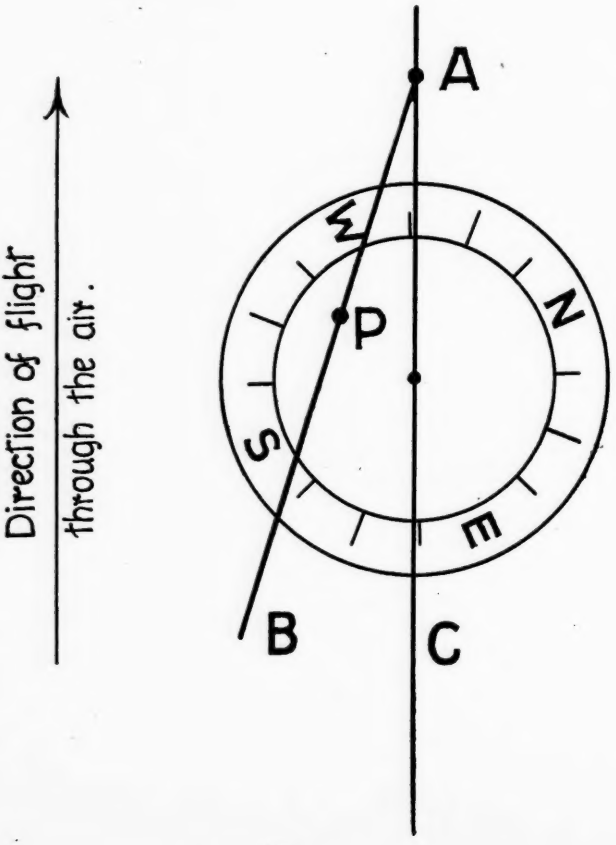


FIG. 4.

A curious and convenient relationship here comes to the air navigator's aid. If he uses a horizontal bearing plate having a transparent centre and lays across it a rod pivoted at one end, as shown in the diagram in Fig. 4, so that its length AB is parallel to the direction of the drift of the ground, AC the line of symmetry being parallel to the fore and aft lines of the machine, and if he then draws a pencil line AB on the bearing plate (previously oriented correctly) and repeats this operation on a number of courses, he will obtain a wind star and the intersection point, known as the wind point, which will give him the velocity and direc-

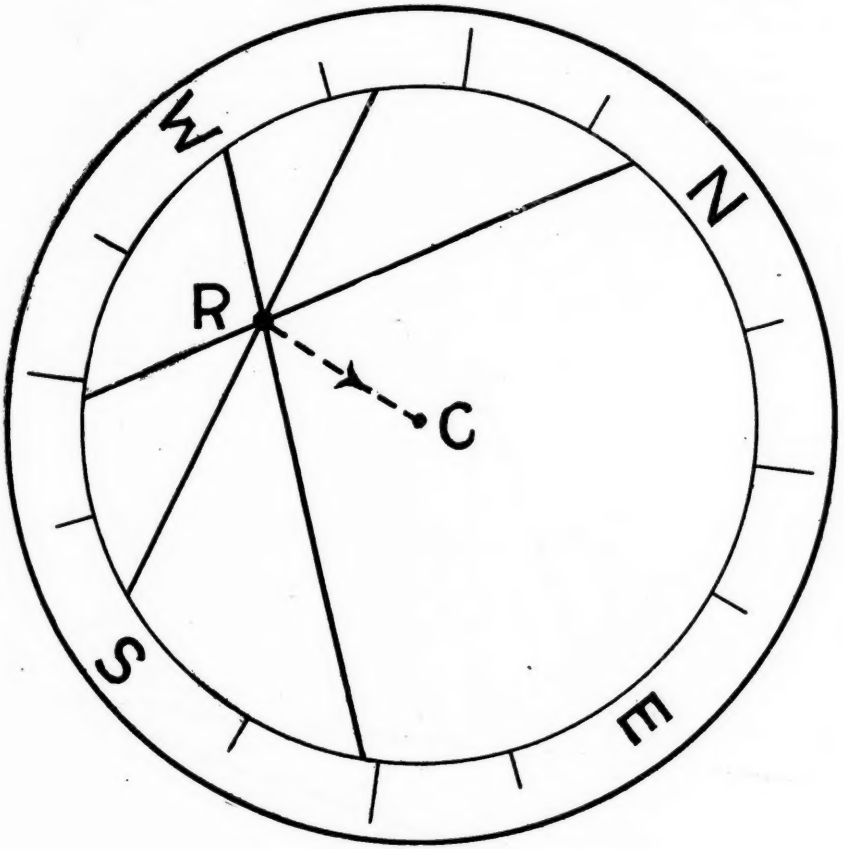


FIG. 5.

tion of the wind. Thus, in Figure 5 three such courses are shown and all, it will be observed, intersect at the wind point R; RC is then the velocity of the wind to scale and the direction of RC relative to the bearing plate scale gives the direction from which the wind is blowing. The point R can of course be got by a cut of two lines only, but for accuracy such change of course should not be less than say 50 degrees; this can conveniently be done by turning first 25 degrees one way, and then the other and for equal times, since this does not interfere appreciably with the course desired to be made good. Of course aircraft on closed patrols, for war purposes, change course several times on each patrol and a wind deter-

mination or check can be made at each "corner." On a long straight flight the position of the wind point along the line AB in Fig. 4 can, if desired, be obtained by timing over some object on the ground and so determining the length of PA and hence the position of the wind point. Equally, once the wind point is obtained, the length PA will give the ground speed and the bar AB can be graduated directly in m.p.h.

The procedure for setting AB to the drift angle depends on the height. At low heights it suffices to view the ground vertically below, but at considerable heights it is much more accurate to observe the angle which an object passed over some minutes previously bears to the fore and aft line of the machine (a tail bearing). When over the sea a flare may be dropped to afford the necessary fixed point when nothing else is available.

So much for the actual use of the method; the reason why the drift lines in Figure 5 all pass through the wind point in this convenient manner may seem to need explanation to those who are not prepared to take such construction for granted.

Thus, in Figure 6, if an aeroplane head due north along CA and the observed drift line be AB we know the closing side of the vector diagram will represent the wind, and that it must start somewhere along the line AB and must end at C. In short AB is what is called a "position line" for the wind point. Now head the craft on a new bearing, say 75 degrees E. of N., along CD and let DE be the observed drift line. Then we get a new vector diagram, and a new position line DE for the wind point; these two intersect at P and this must therefore be

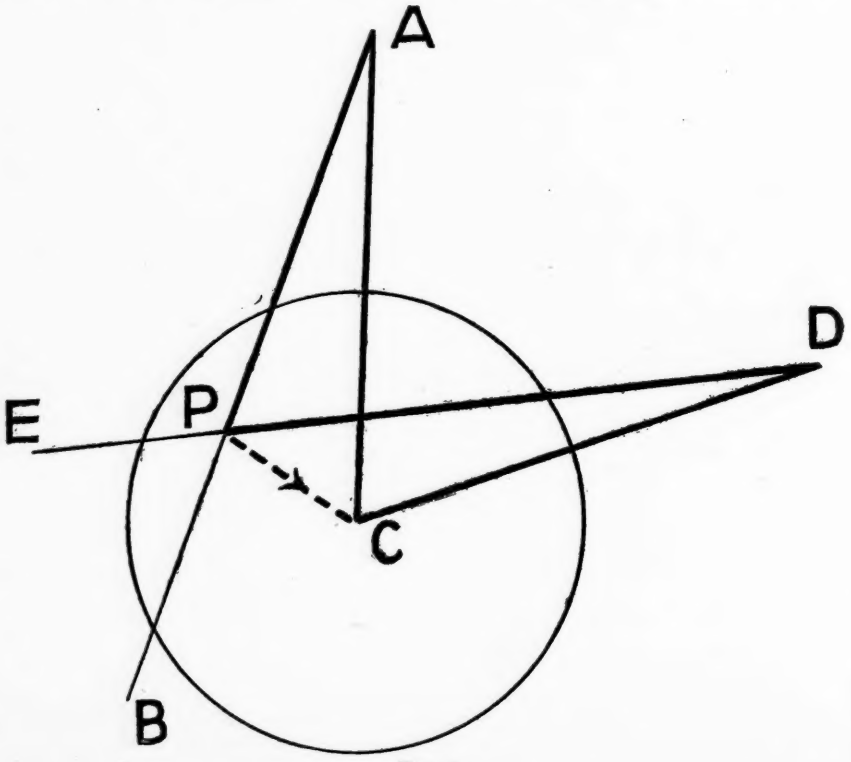


FIG. 6.

the wind point, and PC the velocity and direction of the wind to scale (the scale being the same one as that by which CA and CD represent the air speed).

This is for two courses only, but obviously the drift line for any third, fourth, or additional course must equally pass through the point P. Probably the obtaining of a wind star in this way by flying on several courses in succession affords as accurate a way as can be devised for the ascertaining of the wind elements at any desired altitude and time. Moreover, in the nature of the case, meteorological records must always be received some little time—not infrequently in practice, some hours—after the moment at which they were measured, whereas by this method the instantaneous values can be obtained and can be checked as often as desired.

It should also be noted that AP and DP, in Figure 6, will measure the ground speeds along each of these courses. Hence, once the wind point is found and the instrument set accordingly figures can be given at once for the ground speed along any contemplated course and the probable duration of flight to cover any desired mileage over the ground.

Sometimes—especially in an ocean flight—a suitable object for drift observations will be seen on the earth's surface but it may not be so placed as to be in

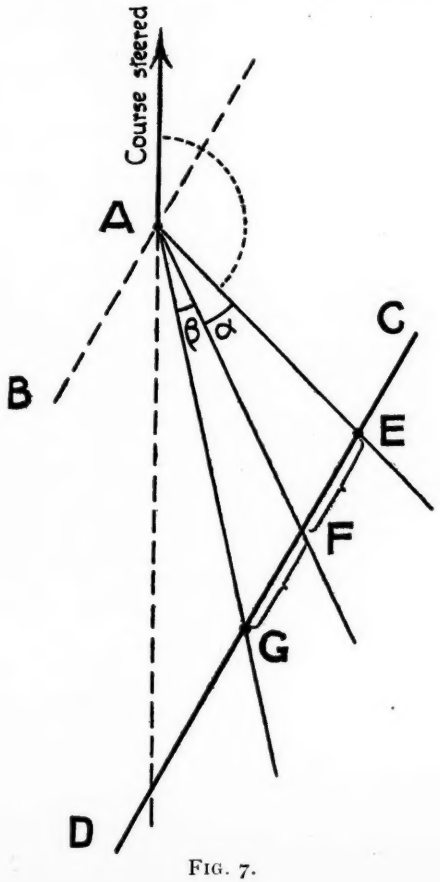


FIG. 7.

the aircraft's path, or it may not be noticed until it is too late to alter course. For such cases the relative path—see Figure 7—instead of being AB may prove to be CD. How is one then to determine the course being made good?

Perhaps the best method is to take times and bearings of the object as it passes through the points E, F and G, such that the time from E to F is equal to the time from F to G. Then if the angles α and β are small, *i.e.*, not more than 20 degrees, it is easy to find CD, the course-made-good, by marking off AE proportional to the angle β and AG proportional to α and then to join FG. Thus, if α be $15\frac{1}{2}$ degrees and β say 13 degrees, we mark off AE at a length of 1.3 inches and AG at a length of 1.55 inches; this gives us the points E and G. Draw a line through these points and we have the bearing of the course-made-good; its inclination to the course being steered will give the drift angle.

With airships the ability to hover can be made use of. If an airship heads up wind and reduces speed until some object below appears stationary, the speed of the airship relative to the air must be equal and opposite to the wind. Hence, the velocity of the wind can be read on the air speed indicator and its direction noted by reading the course being steered.

Whether this method was actually used by the raiding Zeppelin airships I do not know, but it appears that use was made by them of an alternative and less attractive method. This alternative plan was to steer up wind and suddenly to put the ship on a wide circular uniform turn; on completing 360 degrees change of course the ship would, if the wind were zero, be back over the starting point of the turn—in the other event it would be in the rear of this point by a distance equal to the space covered by the wind in the time of the turn. The additional time taken to recover this lost ground at a known air speed, is related to the total of the two times in the same proportion as the wind velocity is to the air speed.

Thus, if T_1 and T_2 be the two times and V the air speed, then

$$\text{wind velocity} = T_2V/(T_1 + T_2)$$

The Prediction of Wind.

Air navigation requires two things of the meteorologists, first that they shall provide accurate information as to the average weather conditions along any specified air route, and secondly that they shall provide a forecast of the probable winds in the upper air during the ensuing two or three days. The former is necessary when planning out standard air routes with their chains of landing grounds, and the latter to enable the navigator to select the best altitude for flight and the probable time table for his journey. Forecasting surface winds is, however, a difficult matter and it may be that the winds of the upper air will prove as little tractable. It happens fortunately, however, that there has, in the last few years, been a great increase in knowledge of the physics of the atmosphere, due in no small measure in this country to the distinguished work of Shaw, Taylor, Gold and Dobson. We may hope therefore that before long the science of meteorology may prove equal even to the considerable demands of the air navigator and his urgent needs.

The ability to predict the upper wind depends upon a knowledge of the pressure and temperature changes in the atmosphere. A few words may perhaps be appropriately inserted here to indicate the method by which this information is utilised. They will indicate the need for further development work in this direction. A knowledge of the barometric pressure throughout a given area enables a series of equal pressure lines, or isobars, to be drawn. The pressure gradient across these lines enables the resulting wind to be calculated; this is known as the gradient wind. The gradient wind is made up of two parts, the geostrophic component and the cyclostrophic component; the former, which is the more important, is due to the earth's rotation and the latter to the curvature of the

isobars. The origin and nature of the geostrophic wind cannot be better described than in the following extract from the official "Barometer Manual," which I take the liberty to quote:—

"Let us consider the case of an arctic bird, or an aeroplane, that starts from some point on the parallel of 84 degrees N., and makes a bee-line for the pole (supposed in sight for the purpose of keeping a straight course) and keeps 'straight on' beyond it, flying at 60 nautical miles an hour. It will reach the pole by direct line after six hours' flight, and at the end of 12 hours will have done a journey of 720 miles and have got to latitude 84 degrees again, and meanwhile the place from which it started will have come round with the earth and have made the journey of about 1,130 miles, and the pilot who has made a straight course will find himself at home again. If he had marked his trail by dropping bombs at intervals or in some other effective manner, he would have provided conclusive evidence that he never 'set out' for the pole at all, but after once getting up speed he made off at a great pace to some point about west-north-west, gradually slackened his speed and got drifted towards the pole, and when he arrived there, turned slowly round and came back to where he started from and arrived at the starting point again from the east-north-east. Whenever anything flies or floats in the air, as airships or winds do, the rotation of the earth has to be reckoned with, and its effect is to turn the course of a body that is left to its own momentum at the rate of 15γ degrees sin λ per hour, where λ is the latitude. On an earth that does not rotate, a body that is left to its own momentum keeps in a vertical plane and moves along a great circle. If the earth rotates the moving body left to its own momentum is diverted from the great circle at the rate of 15 degrees sin λ per hour, to the right in the Northern Hemisphere and to the left in the Southern. If, on the other hand, it is to be kept in the great circle it has to be pushed from the side on which it would be left behind by the rotation of the earth underneath it. The push must always be at right angles to the direction of the motion otherwise it would do more than alter the course, it would accelerate or retard the velocity, and that is not wanted. With a current of air in the free atmosphere we get, so far as we are able to tell, exactly the conditions required, the pressure difference on the two sides of a moving stream of air is always at right angles to its motion, and just provides the push necessary to steer the air with no appreciable effect upon the speed. We get a proper balance, and the air moved under its own momentum without being diverted from its path along a great circle if the push represented by the pressure gradient γ is balanced by a speed of motion v such that

$$\gamma = 2\omega v\rho \sin \lambda$$

when λ is the latitude, ω the angular velocity of the earth's rotation, ρ the density of the moving air."

This formula allows the geostrophic wind to be calculated.

Careful researches along these lines have brought to light a surprising and most fortunate closeness of connection between the geostrophic wind and the actual wind. It is found in fact that the two may without grave error be regarded as substantially identical. Sir Napier Shaw* remarks on this:—

"To assume that this balance of wind and pressure in the upper air is an operative principle of atmospheric structure may be thought a hazardous mode of procedure and it requires the most scrupulous examination, but the proper course seems to be to accept it, at least until the proved exceptions are numerous enough to show that, under the prescribed conditions of motion approximately in a great circle, finite differences of pressure do exist in the air without the compensating velocity in the air currents. It need not be supposed that the balance is always strictly perfect but only that in ordinary circumstances the accelerating forces

* "Manual of Meteorology."

operating in the air are so small in relation to the pressures that we measure, that they are beyond our powers of observation."

Shaw also points out that in ordinary circumstances there is a deviation of some 20 to 30 degrees between the direction of the surface wind and that of the geostrophic wind, due to surface friction and in the direction which that friction would indicate. Dobson has shown that although the geostrophic velocity may be arrived at within 1,000ft. of the earth, the calculated direction will not usually be obtained till 2,500ft.; it follows, therefore, that if the surface friction effects, always local and uncertain, are to be avoided, as accuracy in air navigation requires that they should, flight at a lower height than 2,000 or 3,000ft. over land is undesirable. The effect is much less over the sea and the equivalent heights would be lower. As a general rule the velocity of the surface wind over the sea is one-third less than it would be were there no surface friction; and over the land two-thirds less than it would otherwise be. In the absence of surface friction these velocities would each be that of the gradient wind. This loss of velocity of 33 per cent. over the sea involves the loss of about half the wind's kinetic energy; the missing half is found in the energy of the ocean billows.

Fog is so much the worst enemy the air navigator has to face that it may not be out of place to consider the conditions which govern its occurrence. Fortunately meteorologists are usually able to provide warnings when this danger is likely to be met with, the conditions of its formation being fairly well known. It is known, for instance, that whenever the ground is exceptionally cold so that there is a sharp rise of temperature from the ground upwards and at the same time a slow drift of air over it, there must be fog. This "reversed temperature gradient," as it is called, prevents the air below it from escaping upwards. The air below has a sort of "lid" on it. Thus, over a city a smoky pall will presently spread as the smoke finds itself unable to escape.

It might be expected that in a freely moving atmosphere the temperature would become equalised everywhere, *i.e.*, that it would become isothermal. Owing, however, to the compressibility of the air the law of temperature change is much less simple, being in fact for a well churned atmosphere the same as that which governs the temperature of the air in the compression stroke of an internal combustion engine, *i.e.*, the temperature changes approximate to the adiabatic. Our well churned atmosphere would have not a uniform temperature but one falling off at the rate of one degree Centigrade for each 100 metres of altitude. This condition sometimes arises and when it does the following curious phenomenon occurs, viz., that any body of air which gets slightly more warmed than its neighbour at once rises to the top, since at all positions it is slightly less dense than the surrounding air. Similarly, any portions slightly colder than their neighbours tend to descend to the bottom. Thus, on such occasions the whole atmosphere is very unstable.

When, however, the temperature falls off less rapidly than one degree Centigrade per 100 metres, then the atmosphere is stable. It is very stable when the temperature is isothermal, and exceedingly so under a reversal of gradient. A steeper falling off in temperature than the adiabatic would seem to be impossible.

The bearing of this on fog formation has been pointed out by Sir Napier Shaw following on many observations of the temperature of the air in fog, that "fog is always associated with an inversion of the lapse of temperature with height. The coldest stratum is at the ground and the temperature gradually increases upwards within the fog and for some additional height beyond it. The cloud of fog is the immediate effect of the mechanical convection of cold caused by the mixing of consecutive strata in the turbulence of the eddy-motion and in spite of the fact that the coldness of the lowest layers makes for stability and restrains convection."

Newfoundland fogs are proverbial, and since trans-Atlantic flight may well

start from that Island, the conditions for air navigation on that route seem at first sight somewhat unpropitious. It must be remembered, however, that these particular fogs are chiefly known by their effects on ships, and that the essential danger for air navigation is fog over land, not fog at sea. Fog at sea, like fog anywhere else, is always low lying and can be flown above, but fog over a landing ground is another matter. Fortunately the Governor of Newfoundland is able to report :—*" As a rule the fog does not penetrate inland very far, but is eaten up and absorbed by the land over which it hangs and it is a usual and common daily occurrence to see a bank of fog outside the harbour and a glorious sunny day inside without a vestige of fog." If further inquiry bears out this view the fear that Newfoundland may prove to be a dangerous port for the air navigation may turn out to be unfounded.

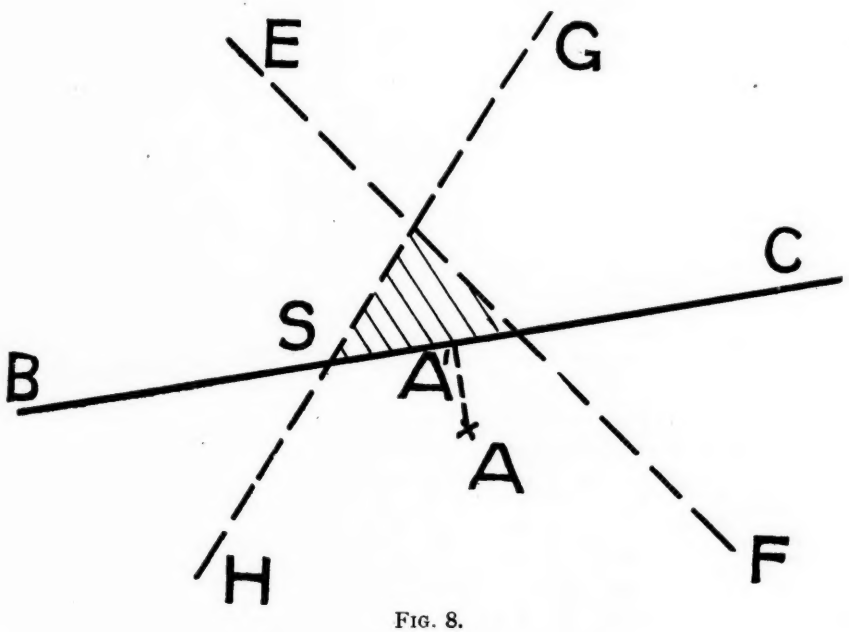


FIG. 8.

Checks on Position.

So much for winds and fogs. We now come to the action which the air navigator needs to take to check his estimate of his D.R. position. In sea navigation, the usual check on the estimated position is by an observation of the sun by day or of the stars by night. A single altitude gives a "position line," *i.e.*, a line on the chart somewhere along whose length the true position of the ship must be. Thus, if in Fig. 8, A be the estimated position and BC a position line found by the observation of some heavenly body, it would be assumed that the real position of the ship would be at A′, since the shift from A to A′ attributes the minimum error to the estimated position. BC is sometimes called a "sumner-line;" mathematically it is the locus of all points in the neighbourhood of A, at which the heavenly body observed has the same altitude. A knowledge of that altitude therefore tells the navigator his position must be somewhere along this

* Report of Civil Aerial Transport Committee, 1918.

line, but it does not indicate the exact spot; for that a second observation is required.

If a further position line such as GH could by some means be obtained, then we should know, within the limits of instrumental and observational error, that the ship's position must be at S. For such a cut to be accurate the angle between BC and GH should not be too small. If a third position line EF were obtainable then the true position would be assumed to be inside the "cocked hat," which is shown shaded.

In air navigation the same methods of observation can be employed, as soon, at any rate, as observational instruments capable of accurate use in the air are available. Numbers of such devices are under trial, but it is too early yet to speak of the results being obtained.

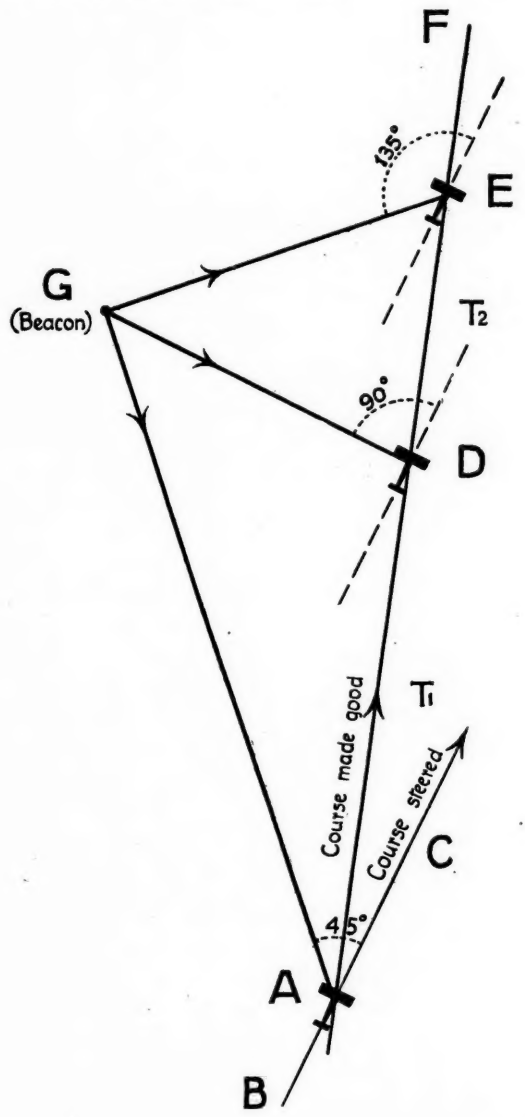
At sea the standard instrument is the sextant. It is used to measure the angular elevation of any heavenly body above the visible horizon. This visible horizon at sea is never a great way off; thus from an observing point 50 feet above the surface of the sea the horizon is but nine miles away. An attempt to use an ordinary sextant from an aircraft, however, brings one up against the serious difficulty that from a height of 5,000 feet the horizon is nearly 90 miles away, and the thickness of air to be passed through is ten times as great as in the previous instance. With the least haze, therefore, a definite line for the horizon will not be found. Quite commonly in fact the "visible horizon" seen from the air is merely the upper line of some haze or cloud lying at an unknown height. To avoid horizon difficulties, an artificial horizon may be employed; this may be either some gravity controlled level or a gyrostatic mechanism. The former is subject to vibration and acceleration errors of rather troublesome amount. Vibration can be reduced by suitable design, but acceleration errors are much more difficult to deal with. Straight steering on a distant mark coupled with an even air-speed are the most fruitful ways of reducing acceleration errors. When no distant mark is visible, use may be made of a turn indicator and the machine be so flown that the radius of curvature of the path is always five miles or more, in which case the lateral acceleration will be limited to about one foot per sec. per sec. corresponding to a maximum error in the level of about two degrees; by taking the average of a number of readings, however, this error can perhaps be reduced to manageable limits.

Gyrostatic means of preserving the level are much more attractive in theory, and thanks to the energy and ingenuity of inventors, there is good prospect of practical success being achieved; but such apparatus is usually inconveniently bulky for such work, and this weighs against its greater accuracy. Time alone will show which method will be the best; possibly each will be found to have a use in which it is the better instrument to employ.

Apart from altitude observations with sextants, azimuth readings will be found advisable—as at sea. This opens up a field for research in which much has yet to be done.

During recent years yet another means of obtaining position lines has been perfected. It has been found possible to determine from an aircraft the compass direction from which wireless waves are being received, and although the time is not yet ripe for a discussion of the methods of operation actually employed some general considerations respecting this method of navigation are well worth discussing. On the assumption that such waves precisely follow great circles in their passage round the earth and that their direction on being received can be ascertained, it is obviously possible, on recognising the signal indicating the beacon station from which the waves are sent, to plot a wireless position line; and if two such beacon stations are sending and are suitably placed, a "cut" may be obtained. Or one such position line may be used in connection

with one or more obtained by astronomical means. Care must be taken in plotting wireless position lines on a mercator chart, since great circles on such charts need to be represented by appropriatelv curved lines.



Note: Tan. drift angle $= \frac{T_1 - T_2}{T_1 + T_2}$

FIG. 9.

The essential point to bear in mind in air navigation, however, is that "estimated positions" by dead reckoning must always be logged; then, that position lines derived from astronomical observations or directional wireless should be obtained as a check on the positions so logged.

A point which may perhaps be worth bringing out is that a combination of bearing and timing observations on a wireless station which is being passed to port or starboard enables the drift angle to be determined without the earth itself being visible. Thus if in Fig. 9 an aeroplane A is steering a course BC and making good a course ADF and the time taken to pass from A where the beacon is on the port bow, to D where it is abeam to port, and from D to E where it is on the port quarter, then the tangent of the angle of drift (the angle DAC) is equal to the difference of these times divided by their sums. This may prove a convenient method of checking the estimated drift angle and so giving a new position line for the wind point.

A method of wireless navigation which has been proposed is for an aircraft to set its head steadily towards a wireless beacon and so make sure of arriving at the desired haven, whether the course steered is otherwise a scientific one or

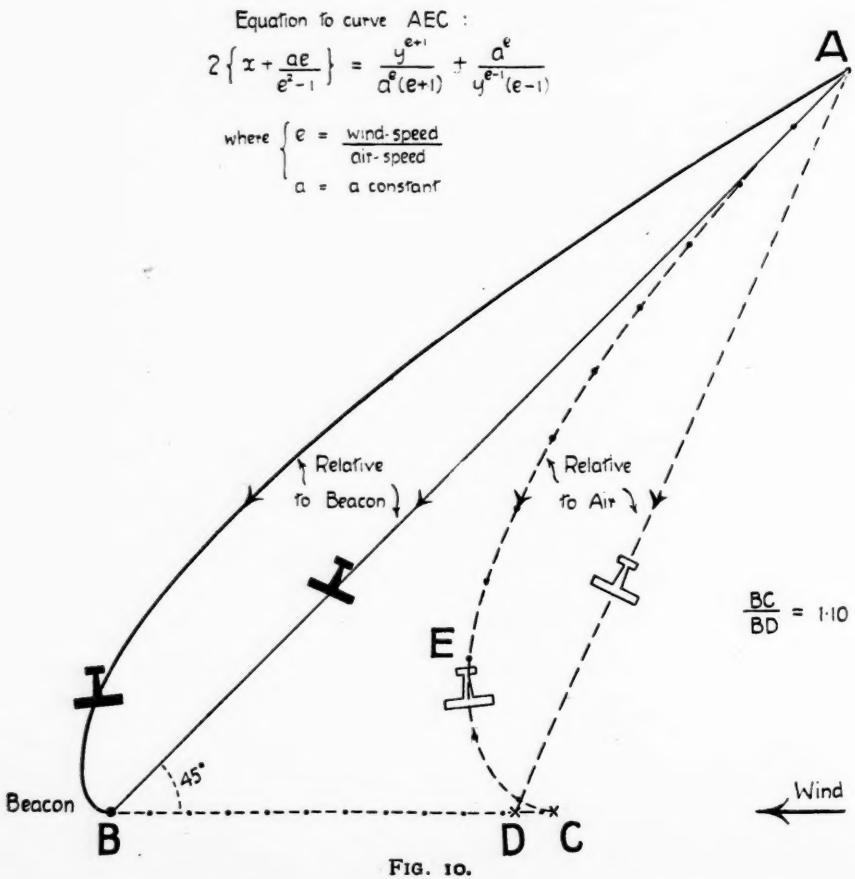


FIG. 10.

not. This will be quite satisfactory in still air, but when there is a high wind blowing it may lead to a somewhat sinuous path. For the existence of wind means that the air ocean has motion relative to the earth; or we may regard the air as still and the earth moving under it at the same speed as the wind, but in the opposite direction—the relative motion is the same Adopting this convention we have a wireless beacon, towards which the aircraft is headed, itself in rapid motion relative to the air. This sets the aircraft on a curved course—the path of a dog running after its master, studied by mathematicians as the "curve of pursuit." In Fig. 10 is seen the path of an aircraft relative to the air under these conditions, with the wind at starting coming over the port quarter with a velocity equal to half the air-speed; and in addition its path relative to the ground. I have also shown by dotted lines the route which would have been followed had the machine been headed with exactly the right allowance for the wind. The "wireless" air path AEC is longer than the correct path AD by 10 per cent., and this requires a correspondingly increased fuel capacity if this method of navigation were adopted under high wind conditions. Similar curves can be drawn for other wind velocities and other wind directions.

Conclusion.

The main conclusion to be drawn, I think, from this short discussion of a subject—yet in its infancy—is first and foremost the need for supporting in every possible way the development of really scientific work in meteorology, not only at observing stations in this country but in every part of the world, particularly in the British Empire—and especially for the study of the physics of the upper air. By taking an active interest in this work and in endeavouring to understand the great advances which have lately been made in the science of meteorological physics, we shall place ourselves in the best position to take advantage for air navigation of what may be called the great oceanic motions of our atmosphere.

PROCEEDINGS.

FIFTEENTH MEETING, 54th SESSION.

The Fifteenth Meeting of the Session was held in the Theatre of the Royal Society of Arts on Wednesday, April 30th, 1919, General R. Brooke Popham presiding.

The CHAIRMAN said it was unnecessary for him to dilate upon the importance of the subject of the lecture to be delivered by Major Wimperis on Air Navigation. An aircraft was an encumbrance unless one could get it where it was wanted. The matter would probably be of even greater importance for civil aviation than it was for military purposes. As a general rule it mattered little whether one dropped a bomb on Frankfort at 6 a.m. or 6 p.m., but if aerial transport was to hold that place in our daily life which was its due, a time-table must be kept to. The Pekin mail will, for instance, have to leave at 10 a.m. daily, without any words " weather permitting " after it. If it was not necessary for him to impress upon his hearers the importance of the subject, still less was it necessary to say anything about the qualification of the lecturer. Major Wimperis was acknowledged to be a master of his subject, and he could not do better than ask him to commence at once.

Major H. E. WIMPERIS, R.A.F., then delivered his lecture.

DISCUSSION.

Major I. O. GRIFFITH said one had heard a great deal in old times of the poetry of the sea, and Major Wimperis had proved that there was also a poetry of the air. But that ended the connection between the sea and the air. What struck one was the need for accurate research. When one started to navigate in air one naturally turned to the sailor, but got very little help there. The sextant as first handed over to airmen had not varied since the time of Newton, and it could hardly be used in the air, even when travelling at 70 or 80 miles an hour. One of the two sextants produced during the last year or so involved an artificial horizon, which ought to have been developed a long time ago by the sister service. He would have liked Major Wimperis to have expressed himself more fully upon the possibility of aerial navigation from one point to another irrespective of weather conditions. How many pilots would guarantee to start from Hendon at 10 o'clock to-morrow morning with the Pekin mail? It was possible that within the next two or three years one would be able to start on flights in clouds or pitch-darkness, but research of a very high order was necessary in the development of methods for locating one's position above clouds and in landing in safety when mist extended nearly down to the ground.

Commander BAKER said his experience of the last four or five years had been connected with the development of the navigation of aircraft of the type Major Wimperis referred to in the latter part of his lecture. It was the application of the ordinary seagoing navigation adapted, in a modified form, to the use of aircraft over the sea, and above clouds possibly. In certain cases the air navigator might obtain a knowledge of the drift of his machine by dropping flares and noticing the way they went astern. But when flying at 10,000 feet over the Atlantic in probably nine cases out of ten there would be so much mist and low-lying cloud over the surface of the sea that nothing in the way of a flare would be visible to the air navigator. Doubtless in the next fortnight or so we should have further

information about that. If, however, dead-reckoning navigation were ruled out of the question as a practical aid to the long-distance air navigator, it came down immediately to the question of providing him with accurate means for fixing his position by astronomical observations or directional wireless. He must either get his bearings from fixed beacon stations or adopt in a modified form the navigation practised for the last two or three centuries by the naval officer. He did not want navigation of quite such an accurate type as the ship's navigator required, as he had no sunken rocks to avoid and he did not want to know his position within a couple of miles. Sometimes if he were 30 miles out—it was only 20 minutes run—it was near enough, but the subject of providing the air navigator with sufficient instruments should not be approached from the point of view that 30 miles was good enough. It was a salutary rule that one should always aim at a much higher degree of accuracy in experimental work than would be required for final results, and the instruments with which the air navigator of the future was to be provided should aim at a constructional accuracy of not more than five minutes, although 30 minutes might be good enough for the airman for his position. As the lecturer pointed out, there were two methods by which the observation of the altitude by the sun and stars could be determined from aircraft by the use of the ordinary sextant used by the ship's navigator. The instrument involved a measurement down to the visible horizon that the air navigator could see. Before the war, in 1914, Colonel Porte was in America with the object of making an attempt to fly the Atlantic in the summer of that year, and he approached the Director of the Compass Department of the Admiralty for advice and assistance as regarded instrumental equipment to enable him to steer his way to the Azores and determine his position by sextant. He (Commander Baker) assisted the Director of Compasses in the elaboration of a scheme for the provision of details for the sextants and of shortened methods of converting the observed altitudes of the sun into position lines on the charts. Colonel Porte at that time realised that one of the difficulties of making astronomical observations lay in the invisibility of the horizon at certain heights, and he decided not to fly higher than 500 feet above the surface of the sea. He (Commander Baker) went up in seaplanes and found that not only was the sea horizon a very bad mark, but nine times out of ten it disappeared altogether. A series of observations was started at Orfordness of the visibility of the sea horizon and continued for a year by the Air Ministry, and the reports upon them gave the impression that nearly every day the horizon would be invisible at 1,000 feet, but if a machine went higher it began to appear again, generally at heights from 4,000 to 6,000 feet. At 6,000 to 7,000 feet he had seen horizons he would only have been too glad to see at times from the deck of a ship. The reports indicated that in the neighbourhood of Orfordness the chance of taking sights of a visible horizon were distinctly greater for the air navigator than for the officer on the bridge of a ship. Whether those conditions prevailed over the wide expanses of ocean nobody, he imagined, knew at present, but as the arrangement of the clouds was likely to be more uniform over the surface of the sea than in a place which had sea on one side and land on the other the same sort of conclusions could be applied to a long-distance flight over sea. The sea navigator, who, to a certain extent, could choose his height, would see the sun and horizon more than a ship's navigator could, and for that reason he advocated a sextant which made use of the visible horizon, rather than an artificial one. Sextants with bubbles, pendulums or gravity-controlled arrangements had been often tried in ships, but were never satisfactory, except in flat calms. In such a sextant the pendulum or bubble did not show the true vertical, but the false vertical of the moment produced by horizontal acceleration, and the horizontal accelerations were generally greater in the air than in a ship even in the worst case of rolling. He had made a calculation as to what would be necessary in the way of piloting a machine if the navigator could have at his disposal a vertical which did not err by as much as five minutes of arc at the time when an observation was taken. The results could be expressed thus:—There would be an

acceleration in the fore and aft direction of the machine if the engine were not pulling uniformly, similar to the case of a pendulum hung in a tube train, which would swing a number of degrees out of the vertical when the train pulled up. If the pendulum was not intended to swing more than five minutes from the vertical the machine must not accelerate at a greater speed than 2 m.p.h. per minute. During the 10 seconds during which the navigator was taking an observation the machine would have to keep her speed constant with an accuracy of about one-third m.p.h., which he was told was not "within the region of practical politics." To take an alternative case, if a machine were turning upon a circle of very long radius the pendulum would swing outwards, like the horses on a roundabout. The angle must not exceed five minutes of arc, from the navigator's point of view, and to keep within those limits a machine travelling at 100 m.p.h. must be steering on a curve with a radius of not less than about 100 miles, equivalent to her not altering her course at a greater rate than one degree per minute. His experience in using sextants (plumb line, pendulum and bubble) was that they followed absolutely the horizontal accelerations of the machine; and any single observation was as likely as not to be two degrees wrong, and that meant that one's position line on the surface of the earth was 120 sea-miles out.

Lieutenant-Colonel HOLT was of the opinion that navigation was at present a long way ahead of meteorology, and that if a pilot now had correct meteorological readings he could hold his course for a considerable time. On the Western Front in France at the beginning of the war meteorological reports were very bad, but at the end they were very good, and pilots had great confidence in the data given them. They were made good by an intricate system of wireless and telephones, but now the reports had gone back to their old state, and a pilot would be justified in hesitating to accept the assurance of the meteorological people that conditions were all right before starting over the Atlantic. What was wanted was a quick and accurate system, not of forecasting, but stating what the existing weather was on the route one was going to fly over. There should be a large number of stations reporting at stated hours the state of the weather in a form which the pilot could understand. At present one got a report as to whether it was fit or unfit, and there was considerable doubt whether the man who made the report knew what he was talking about. A system of observation posts was wanted, with reliable accurate people, who would give the pilot the information and let him make up his mind. He should be informed of the height of the clouds, the direction and strength of the wind. Fog was the principal thing about which pilots wanted absolutely accurate information. Pilots now found their way by maps with geographical names on them. Would it not be well to devise some universal scheme for the Continent and the British Isles of dividing the country into numbered squares and marking the number on towns, so that a pilot could tell roughly where he was. A similar system could be used at night, by having lighthouses flashing different signals. The people who invented the instruments used in cloud flying had tremendous faith in them, and they were good, but there had been little practice in their use, because few of the instruments were available during the war. There were just enough to train pilots. If the machines for overseas had been equipped with them cloud flying would have got much further than it had done. He would like to ask General Maitland why the Germans during the Zeppelin raids failed so badly in their navigation. They failed nearly every time to make their landing without asking where they were.

Major STEWART said he thought the Armistice was responsible for cloud flying not having been carried to a point which would enable the Pekin mail to leave regardless of weather. He could not see how civil aviation could be possible unless the question of finding one's location above the clouds were solved. As the result of work at Orfordness it was possible to travel distances up to 100 miles above the clouds and come out within five or six miles of the proper objective.

Just after September considerable efforts were put forward by Major Taylor in conjunction with the Independent Air Force towards making above-cloud flying into Germany possible. Had any practical tests been made in finding out the drift by the abeam bearing? If the drift had to be found by measuring two consecutive angles in conjunction with a stop watch it was difficult to get accuracy, apart from the question of plotting afterwards.

General E. MAITLAND said airship officers had been wondering why the Zeppelins in the North Sea gave away their position. It was thought they were in a panic. Our people always knew where they were, and accurate courses were plotted. The position of every Zeppelin which made a wireless call was accurately known at any time during any of their flights across the North Sea.

Major CHRISTIE said with the climatic conditions and the utter lack of information from the meteorological stations in this country, the average flier would be well advised to keep below the clouds when putting off for long distances. If one wanted to get to Edinburgh he got information from Norwich. The heights of the clouds were hardly to be relied on at all, and that was an important factor. He thought maps would probably be the chief means of aerial navigation for some time. If one tried to sail above the clouds for six hours and drop on Edinburgh or Glasgow, he might come down 20 miles from Edinburgh with his altimeter still showing 3,000 feet and sail gaily into the Grampian Mountains. A machine might come from France or Germany and find this country thick in fog. Experiments might well be made on landing in fog. He did not see why there should be any serious difficulty. It was on a par with landing into the centre of an aerodrome on a dark night. The main aerodromes in the country send up small captive balloons, the entrance balloon, down-wind, being a different shape or defined in some way from the up-wind balloon, and one ought to be able to get the standard glide down between the balloons by working a pitot tube having one's gliding speed and taking into consideration the rate of the engine. The diving angle should be fixed for every machine. The entrance balloon was above the aerodrome, and the standard glide had to be settled according to the distance to the other balloon, towards which one had to steer until the ground was struck. A little arrangement could easily be devised, such as a bulb on a winch, and let out a certain distance below the undercarriage, which would indicate the height of the machine, by putting out a light on the dashboard when the bulb touched the ground. Then the control lever was pulled back and the landing made.

Dr. LINDEMANN said that after hearing so many strictures upon the gravity controlled sextant he did not know whether he dared say anything in its favour. He himself had found that it was possible in practice to obtain an accuracy of about $\frac{1}{4}$ degree. To do this one had to fly straight, a problem that was much easier of solution when one could steer for a conspicuous distant object on land than it would be over the sea. Here some gyro-stabilised azimuth indicator or turn indicator would be required, since it would be asking too much of the Compass Department to expect them to design a compass which would enable the pilot to fly straight within one degree. He cordially agreed with Major Wimperis' desire that research of every kind should be encouraged, and would like to emphasise the importance of pure research, which did not appear to be likely to lead to results of any practical use. Thus, for example, though research on the ionisation of gases or their absorption coefficients for infra-red rays, might not appear to be of practical interest, yet the whole future of aerial navigation might well depend upon these problems. Undoubtedly one of the most convenient forms of navigating was by means of directional wireless. But directional wireless was subject to errors of several degrees. These errors were due to variations in the height and ionisation of the conducting layer in the upper air, and unless they could be systematised and predicted navigation by directional wireless would never be reliable. The only hope lay in a close study in the laboratory of the phenomena of gaseous ionisation and the way it was produced in the higher layers of the

atmosphere. Again, take the problems of cyclones, on which our weather depended. Cyclones were due to variations at heights between 10 and 20 k.m. in the air, *i.e.*, outside the part in adiabatic or convective equilibrium and in the isothermal region. That an isothermal region existed was due to the absorption of infra-red radiation by carbonic acid and water vapour in those regions outweighing the transference of heat by convection. Cyclones were therefore certainly caused by some abnormal radiation or absorption effect in these or other gases. The absorption and scattering of long-wave radiation as well as the emission of different surfaces could only be studied adequately in a laboratory. Until these phenomena had been cleared up there seemed little hope of any real advance of meteorology, and aerial navigation would remain a hazardous and unreliable means of communication.

Lieutenant-Colonel WARRINGTON MORRIS said the lecturer referred invariably to miles per hour. When one started working on a Mercator Chart it was done in nautical miles. The two methods should not be used, otherwise errors would be made. Investigations were already in hand with regard to deflections in wireless waves, which were certainly deflected, by coast line for instance, and there was a large field to be covered in ascertaining the deflections in various parts of the world. With regard to fixing one's position by directional wireless, it must be remembered in fixing one's position in the middle of the Atlantic that any beacon station on the ground was at least 1,000 miles away and that every degree of error in taking a bearing from such a station would make an error of about 15 miles for every 1,000 miles. In a machine, two degrees of error would be very good, and in that case there would be an error of 30 miles. The proposal to fly direct on beacon stations was only made to save any navigational instruction to the pilot. If pilots were to be trained in navigation, fixed coils in the machine and a compass could be used, and the drift would have to be found by seeing how much the compass bearing altered by turning the machine direct on the station at certain intervals.

Mr. G. BRODSKY said during the war designs of apparatus were made in a hurry and contracts were made and executed in a hurry and the best possible was not always obtained. The latest model of course-setting bomb-sight, designed and produced just before the end of the war, had not been brought out for general use, and, in his opinion, that particular sight was the only one that could give accuracy in navigation. Research should be continued with unabated vigour, and a considerable amount of public funds devoted to it.

Mr. C. E. MENDENHALL (Scientific Attaché to the American Embassy) said that during the last eight months of 1918 several people in the U.S.A. Air Service gave a great deal of attention to taking astronomical observations from aeroplanes by means of the much-abused sextant. Their experiences had been more encouraging than might have been expected, judging by the opinions he had just heard. They did reasonably satisfactory work with the sextant and pendulum artificial horizon, and they got along quite comfortably with a bubble sextant, which was developed by Dr. Wilson, the Astronomer connected with Harvard University. Dr. Russell worked with it, and was pleased with its behaviour. The anomalies in regard to directional wireless which had been described during the last year and a half were somewhat discouraging, but more research should be carried on until the nature of the difficulties was more understood and a way of avoiding them was found. The meteorologist had been coming in for the hard end of things to-night, but it was a pretty stiff question to ask him what the force and direction of the wind were at a height of 5,000 feet above clouds which were assumed to cover the whole of this island, and indeed about as difficult to answer as it would be to fly above the clouds without the information.

Major C. H. KEITH said he thought the lecturer would agree that measurements of drift made from Pitot tubes were difficult and would probably be

inaccurate. At a height of 10,000 feet or over a small angular change made a very big difference. One had nothing to indicate whether one was flying slightly wing-down. Flying by compass was not easy, and pupils required a great amount of training to it. In dead-reckoning flying seaplanes had gone off and lost sight of the coast, and after a 60-mile flight, with a visibility of five miles, it had been possible to hit off the objective with a small error, perhaps half a mile and perhaps a minute or a minute and a half. The present air-speed indicator could be used for obtaining the actual speed at which the machine was passing through the air. This was useful, but liable to errors, and corrections had to be made for change of altitude, change in the barometer and change in the temperature. With altimeters it had been observed that errors crept in of as much as 300 feet. That was serious as regarded the accurate setting of bomb sights. Had any information been gathered as to how the isobars varied with altitude? Tables had been made from observations from kite balloons, but only, as far as he knew, for comparatively low altitudes. The figures that used to be sent from ships were only surface observations, but one wanted the velocity and direction of the wind at reasonable flying altitudes. Everyone was pinning his faith to wireless navigation. Prof. Fessenden had made important observations on distortion of wireless waves forms at sunrise and sunset and moonrise and moonset, due to the shadow wall which ran north and south, under which conditions there was great distortion on the neighbourhood of receiving and transmitting stations. Working with beacon stations east to west seemed liable to serious errors if the shadow wall occurred between the aircraft and the station. The mooring ropes of marking balloons were likely to cause difficulties to aircraft. Some long while ago it was suggested that fog might be broken up in the vicinity of stations by vortex rings. Charts should be standardised. Some people, who wanted to show how fast a machine flew, used statute miles, while other figures were given in nautical miles. It would be simpler to have a standard chart, with one class of mileage.

Lieutenant BIDDLECOMB asked whether there was any method known by which the spherical triangle could be solved mechanically, with little calculation by the pilot. There were likely to be errors of calculation by the pilot. Such a mechanical method was required before the sextants could be used.

Major MAYO said when the war started the compass used was practically useless. It suffered from such serious errors as the vibrational and northerly turning errors. The late Keith Lucas, who was a distinguished physiologist at Cambridge, gave up his work, and devoted his extraordinary instrumental skill to solving the problem of the aeroplane compass. He directed a research at Farnborough which took him into the air hundreds of times, and he evolved the R.A.F. Mark II. compass, which eliminated the errors of the previous compasses, and it had been the basis of practically all subsequent navigational research, and subsequent compasses were based on it. Unfortunately, Keith Lucas was killed in an aeroplane accident. He (Major Mayo) thought that was a suitable occasion on which to pay some tribute to his distinguished work.

The LECTURER, replying to the discussion, said he endorsed Major Mayo's tribute to Keith Lucas' splendid work at Farnborough. The success that had been met with in turn indicators might give the magnetic compass a lease of life which few of its supporters believed possible a few months ago. A modern turn indicator enabled a machine to be flown so straight that the lateral acceleration was not too great for a magnetic compass to take charge of it. Mr. Sperry had told him early in this year of a gyro-compass he was getting out for aeroplane use and also a gyrostatic turn indicator, but he confessed that in view of the accuracy obtainable by using the turn indicator he was not sure that further work on the compass might not prove to be beside the point. A most desirable thing was that some means should be found by which the pilot might feel safe in flying above clouds. In the case of the present Cologne mail service the machines

on bad days flew from 30 to 50 feet above the ground, not daring to go above the clouds. Commander Baker had done aviators a good service in taking the horizon type of sextant and endeavouring to get it to a perfect state. When he (the lecturer) limited the degree of accuracy he was not limiting the accuracy of Commander Baker's instrument, but referred to the inaccuracy caused by the unpleasant habit cloud horizons had of being at different altitudes. Accurate work had been done with the bubble sextant, both here and in America, and he thought they might work satisfactorily, particularly when we had the turn indicator to reduce the acceleration. Probably the mean of four or five measurements would give the position to a quarter of a degree (15 nautical miles). Certainly one of the great difficulties was to get meteorological information sufficiently quickly to the people who could use it. The International Conference in Paris had drawn up an international method of marking aerodromes. If the Armistice had come a few months later more progress would have been made in cloud flying. He did not think abeam angles had been used for directional flying. The question was worth consideration by the Research Department. He congratulated Prof. Lindemann on his brilliant appointment at Oxford. Perhaps the naval practice of marking everything by knots was the best. It did not matter whether the air-speed indicator was marked in miles per hour or knots, as it had to be converted for the lower density of the air. He would expect a mechanical apparatus for solving spherical triangles would have the disadvantages that it would have to be bulky and heavy to enable it to be read in the air. One was reduced for great accuracy to tables and for intermediate accuracy to graphs. Possibly the d'ocagne nomogram might prove a convenient method of solving the spherical triangles which occur in air navigation.

The CHAIRMAN said he thought Major Christie had always used the instrument that was used in France in 1915 for landing in fog. It consisted of a little weight at the end of a string, which put out an electric light when it touched the ground. It was fairly successful, but was given up because they took to lighting up the aerodromes properly. There had been an enormous collection of meteorological data, but very little research proper, and that was a thing that should be tackled now—whether by the Air Ministry or other Government Department he did not know. Cloud flying had a psychological effect on pilots. Though trained in cloud flying at Orfordness they did not seem keen on doing it in France. He proposed a hearty vote of thanks to the lecturer.

Major-General R. W. RUCK (President of the Society) moved a vote of thanks to General Brooke Popham for presiding, and congratulated him on his distinguished and important appointment as Director of Research at the Air Ministry.

ABSTRACTS.

Summary of Paper on "Airships," by Wing-Commander Cave, delivered to the Engineering Section, British Association.

The paper is intended to set out the present difficulties in development and the lines along which future research is required.

The principal difficulty experienced with the use of airships in tropical climates is the deterioration of the strength and gastightness of the fabric under the action of light. The gastightness of the bags of a rigid ship is obtained by goldbeaters' skin, the supply of which is very limited, and a substitute of equal gastightness and low weight is badly wanted.

An important function of the outer cover of a rigid ship is to reflect as much as possible of the light and heat which falls upon it. This is necessary in order to reduce the superheating of the gas to a temperature above that of the surrounding air thereby causing a false lift which decreases as soon as the intensity of radiant heat is reduced.

The reinforcement of non-rigid envelopes is discussed. It is suggested that fabric, which is usually of equal strength in both warp and weft directions, should be reinforced by circumferential bands of string tape which will supply the excess of the circumferential tension over the longitudinal tension.

Attention is drawn to the relative unimportance of permeability to hydrogen as compared with ability to resist the passage of air into the gas space, as air which has leaked in can only be eliminated by the discharge of large quantities of gas.

The importance of being able to take weight into the ship during flight to compensate for superheating or for petrol consumed is discussed.

Experiments have been made in using hydrogen as supplementary fuel. It is found that the use of hydrogen alone causes excessive detonation, but by suitably proportioning the mixtures of hydrogen and petrol, satisfactory running can be obtained and very considerable economy of fuel achieved.

Attention is drawn to the much greater relative importance of fuel economy than engine weight which obtains in an airship by reason of the much greater duration of flight. The need of accessibility and ease of repair during flight are discussed and also various minor aspects in which the ideal airship engine differs from that of the aeroplane.

The desirability of having a propeller of variable pitch and one capable of sufficient variation to produce reverse thrust is discussed.

Attention is drawn to the necessity of obtaining some method of determining the height of an airship by means other than barometric pressure, so that the reading of the barometer at a point on the ground below the airship can be taken for meteorological purposes.

Attention is drawn to the improved ratio of weight carried to fuel expended which results from increased size. It is shown that the limitation to the size of a rigid airship is set by the diameter of cross-section which is possible in view of the lateral pressure of the gasbags when unequally inflated. In the case of a non-rigid ship without effective transverse bulkheads the limitation to size is probably set by the accumulation of pressure at the upper end of a long ship when at a considerable angle of pitch.

It is shown that a non-rigid ship of 500,000 cubic feet capacity and a rigid ship of 2,000,000 cubic feet capacity are each capable of carrying a useful weight equal to about 50 per cent. of their displacement. The relatively high ratio in the case of non-rigid ships renders it most desirable that ships of this type should be developed and considered where the loads to be carried and the distances to

be covered are not so great as to render the more expensive rigid construction necessary.

Particulars are given of the recent success obtained in mooring out a rigid airship to a mast. She remained for three weeks in charge of watches, each consisting of one N.C.O. and five men, and experienced gusts up to 43 m.p.h., very heavy rain, bright sunshine, and several thunderstorms, including one of exceptional violence. This development is one of the greatest importance as it materially reduces the difficulties of landing and handling an airship.

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